Study of Single-Spin Asymmetry in Diffractive High- p_t- Jet Production.

S.V.Goloskokov [1]

Bogoliubov Laboratory of Theoretical Physics, Joint Institute for Nuclear Research.
Dubna 141980, Moscow region, Russia.

Abstract

It is shown that the transverse single spin asymmetry in polarized diffractive $Q\bar{Q}$ production depends strongly on the spin structure of the pomeron coupling. It is concluded that the spin properties of quark-pomeron and proton-pomeron vertices can be studied in future HERA-N experiments.

[1] Email: goloskkv@thsun1.jinr.dubna.su

1 Introduction

It is well known that large spin asymmetries are observed in different high-energy reactions. Extensive information about spin-dependent distributions inside a hadron can be obtained from double spin asymmetries [1]. However, it is necessary to have two polarized particle beams (or a polarized beam and a target) to study such asymmetries. For hadron high-energy reactions it will be possible in RHIC.

A very important information on spin properties of QCD can be obtained ¿from transverse single spin asymmetry. Single spin asymmetry differs from double spin asymmetries and depends strongly on the hadron–wave–function properties and is determined by the relation

$$A = \frac{\sigma(^{\uparrow}) - \sigma(^{\downarrow})}{\sigma(^{\uparrow}) + \sigma(^{\downarrow})} \propto \frac{\Im(f_+^* f_-)}{|f_+|^2 + |f_-|^2}, \tag{1}$$

where f_+ and f_- are spin-non-flip and spin-flip amplitudes respectively. So, single spin asymmetry appears if both f_+ and f_- are non-zero and there is a phase shift between these amplitudes. It can be shown that the spin-flip amplitude is of the order of magnitude

$$f_- \propto \frac{m}{\sqrt{P_t^2}} f_+.$$

Moreover, an additional loop in the amplitude is important to have a phase shift between amplitudes. As a result, we have

$$A \propto \frac{m\alpha_s}{\sqrt{P_t^2}}. \tag{2}$$

It has been shown in [2] that the mass m in (2) is of the order of the hadron mass. So, we can expect large transverse asymmetry for $P_t^2 \simeq$ Few GeV^2. For such momenta transfer the diffractive processes should be important.

Diffractive production of high p_t jets has been observed experimentally at CERN and HERA in hadron-hadron collisions and deep inelastic lepton-proton scattering [3]. Such processes where a proton remains intact are determined at high energies by the pomeron exchange. These experiments have been initiating various investigations of the diffractive reactions and pomeron properties.

The pomeron is a colour–singlet vacuum t-channel exchange that can be regarded as a two-gluon state. The pomeron contribution to the hadron high-energy amplitude can be written as a product of two pomeron-hadron vertices $V_{\mu}^{hh I\!P}$ multiplied by some function $I\!P$ determined by the pomeron. As a result, the quark-proton high-energy amplitude looks as follows

$$T(s,t) = i I\!P(s,t) V_{qq I\!P}^{\mu} \otimes V_{\mu}^{pp I\!P}. \tag{3}$$

In the nonperturbative two-gluon exchange model [4] and the BFKL model [5] the pomeron couplings have a simple matrix structure:

$$V_{hh I\!P}^{\mu} = \beta_{hh I\!P}\, \gamma^{\mu}, \tag{4}$$

which leads to very small spin-flip effects. We shall call this form the standard coupling.

However, the experimental study of transverse spin asymmetries in diffractive reactions shows that at a high energy and momentum transfer $|t| > 1GeV^2$ they are not small [6] and can possess a weak energy dependence. This means that the pomeron can be complicated in the spin structure [7, 8].

The structure of the pomeron-proton coupling is significant in the explanation of transverse asymmetries. Information about this coupling is rather limited. Model approaches show that the pomeron–proton vertex is of the form

$$V_{pp I\!P}^{\mu}(p,r) = m p_{\mu} A(r) + \gamma_{\mu} B(r). \tag{5}$$

The amplitudes A and B in (5) are determined by the proton wave function and can be calculated within models approaches (see e.g. [7, 9]). For spin-averaged and longitudinal polarization of the proton, the B term is predominant. As a result, the longitudinal double spin asymmetry does not depend on the pomeron-proton vertex structure. The situation is drastically different for single and double spin asymmetries with a transversely polarized proton. In this case both functions, A and B, contribute. Really, in some models the amplitudes A and B can have a phase shift. As a result, there appears the single spin asymmetry determined by the pomeron exchange:

$$A_{\perp}^{h} = \frac{2m\sqrt{|t|}\Im(AB^*)}{|B|^2}. \tag{6}$$

Here the $|A|^2$ term is omitted in the denominator. So, the knowledge of all spin structures in the pomeron-proton vertex is important here. The model [7] predicts that the asymmetry at $|t| > 1GeV^2$ can be about $10 \div 15\%$.

The form of quark-pomeron coupling may be not so simple as in (4). The perturbative calculations [10] for this vertex give:

$$V^{\mu}_{qq\mathbb{P}}(k,r) = \gamma_\mu u_0 + 2mk_\mu u_1 + 2k_\mu \not{k} u_2 + iu_3\epsilon^{\mu\alpha\beta\rho}k_\alpha r_\beta \gamma_\rho\gamma_5 + imu_4\sigma^{\mu\alpha}r_\alpha. \quad (7)$$

Here k is a quark momentum, r is a momentum transfer. The spin structure of the quark-pomeron vertex (7) is drastically different from the standard one (4). Really, the terms $u_1(r) - u_4(r)$ lead to the spin-flip at the quark-pomeron vertex in contrast to the term proportional to $u_0(r)$. The functions $u_1(r) \div u_4(r)$ at large r^2 are not very small [11]. Note that the phenomenological coupling $V^{\mu}_{qq\mathbb{P}}$ with u_0 and u_1 terms was proposed in [12].

The nature of appearance of the new structures in the pomeron coupling (7) is similar, e.g., to an rising of the anomalous magnetic momenta of a particle. Really, if we calculate the single gluon loop correction to the standard vertex (4) for the massless quark, we obtain the following structure (momentum definitions are as in (7))

$$\gamma_\alpha(\not{k} + \not{r})\gamma_\mu \not{k}\gamma^\alpha \simeq -2[2(\not{k} + \frac{\not{r}}{2})k^\mu + i\epsilon^{\mu\alpha\beta\rho}k_\alpha r_\beta \gamma_\rho\gamma_5]. \quad (8)$$

So, in addition to the γ_μ term we obtain immediately from the loop diagram the contributions equivalent to u_2 and u_3 in (7). Expression (7) can be regarded as a model for the effective quark-pomeron coupling because only planar graphs have been considered. However, we hope that the nonplanar diagrams that was excluded from the analysis [10] give a sufficiently small contribution at moderate momenta transfer.

This new form of the pomeron–quark coupling should modify various spin asymmetries in high energy diffractive reactions [12, 13]. It was found from the analysis of longitudinal double spin asymmetries that the main contribution is connected with u_0 and u_3 in (7). The axial-like term $V^\mu(k,r) \propto u_3(r)\epsilon^{\mu\alpha\beta\rho}k_\alpha q_\beta\gamma_\rho\gamma_5$ is proportional to the momentum transfer r and thus contributes only in diffractive reactions where the pomeron has a non-zero momentum transfer ($r^2 = |t|$). So, this new $u_3(r)$ term does not change the standard pomeron contribution to the proton structure functions because here the pomeron momentum transfer is equal to zero.

The aim of this report is to study the pomeron-coupling effects in single spin asymmetry in pp diffractive high p_t-jet production. Future HERA-N facilities [14] is a good place to perform such investigations.

2 Spin asymmetry in diffractive reactions

Let us investigate single transverse spin asymmetry in the $p \uparrow p \to p+Q\bar{Q}+X$ reaction. The standard kinematical variables look as follows

$$s=(p_i+p)^2,\ t=r^2=(p-p')^2,\ x_p=\frac{p_i(p-p')}{p_i p}. \tag{9}$$

This process is determined at small x_p by the diagram in Fig.1.

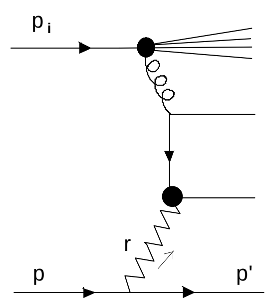

Figure 1: Diffractive $Q\bar{Q}$ production in pp reaction.

The cross sections σ and $\Delta\sigma$ can be written in the form

$$\frac{d\sigma(\Delta\sigma)}{dx_p dt dp_\perp^2}=\{1,A_\perp^h\}\frac{\beta^4|F_p(t)|^2\alpha_s}{128\pi s x_p^2}\int_{4p_\perp^2/sx_p}^{1}\frac{dy g(y)}{\sqrt{1-4p_\perp^2/syx_p}}\frac{N^{\sigma(\Delta\sigma)}(x_p,p_\perp^2,u_i,|t|)}{(p_\perp^2+M_Q^2)^2}. \tag{10}$$

Here g is the gluon structure function of the proton, $p_\perp$ is a transverse momentum of jets, M_Q is a quark mass, $N^{\sigma(\Delta\sigma)}$ is a trace over the quark loop, β is a pomeron coupling constant, F_p is a pomeron-proton form factor. In (10) the coefficient equal to unity appears in σ and the transverse hadron

asymmetry $A_\perp^h$ at the pomeron-proton vertex determined in (6) appears in $\Delta\sigma$.

The main contributions to $N^\sigma (N^{\Delta\sigma})$ are determined by u_0 and u_3 structures in (7). They can be written in the form for $x_p = 0$:

$$\begin{aligned} N^{\Delta\sigma} &= 16(p_\perp^2 + |t|)p_\perp^2 u_0^2 + \Delta N^{\Delta\sigma}; \\ N^\sigma &= 32(p_\perp^2 + |t|)p_\perp^2 u_0^2 + \Delta N^\sigma. \end{aligned} \tag{11}$$

where

$$\begin{aligned} \Delta N^{\Delta\sigma} &= 8[(p_\perp^2 + |t|)u_3 - 2u_0](p_\perp^2 + |t|)p_\perp^2 |t| u_3; \\ \Delta N^\sigma &= 16[(p_\perp^4 + 4p_\perp^2|t| + |t|^2)u_3 - 2(2p_\perp^2 + |t|)u_0]p_\perp^2 |t| u_3. \end{aligned} \tag{12}$$

Note that $u_3 < 0$.

Both σ and $\Delta\sigma$ have a similar dependence at small x_p

$$\sigma(\Delta\sigma) \propto \frac{1}{x_p^2}$$

This important property of (10) allows one to study asymmetry at small x_p where the pomeron exchange predominates because a high energy in the quark-pomeron system.

We shall calculate integrals (10) using the simple form for the gluon structure function

$$g(y) = \frac{R}{y}(1-y)^5, \quad R = 3.$$

This form corresponds to the pomeron with $\alpha_{I\!P}(0) = 1$. Just the same approximation for the pomeron exchange has been used in calculations. The analysis can be made for the pomeron with $\alpha_{I\!P}(0) = 1 + \delta$ ($\delta > 0$) and more complicated gluon structure functions but it does not change the results drastically.

In the diffractive jet production investigated here the main contribution is determined by the region where the quarks in the loop are not far of the mass shell. Then the interaction time should be long and the pomeron rescatterings can be important. They change properties of single pomeron exchange. This type of the pomeron is called usually the "soft pomeron". It can have a spin-flip part with a phase different from the spin-non-flip

amplitude [7]. So, we can assume that the hadron asymmetry factor in (10) can be determined by the soft pomeron that coincides with the elastic transverse hadron asymmetry (6). In our further estimations we shall use the magnitude $A^h_\perp = 0.1$.

The calculations were performed for the magnitude $\beta = 2GeV^{-1}$ [15] and the exponential form of the proton form factor

$$|F_p(t)|^2 = e^{bt} \quad \text{with} \;\; b = 5GeV^2.$$

We used the simple form of the $u_0(r)$ function:

$$u_0(r) = \frac{\mu_0^2}{\mu_0^2 + |t|}, \quad r^2 = |t|,$$

with $\mu_0 \sim 1Gev$ introduced in [15]. The functions $u_1(r) \div u_4(r)$ at $|t| > 1GeV^2$ were calculated in perturbative QCD [11].

Our predictions for σ and single spin asymmetry at the HERA-N energy $\sqrt{s} = 40GeV$, $x_p = 0.05$ and $|t| = 1GeV^2$ for the standard quark-pomeron vertex (4) and spin-dependent vertex (7) are shown in Figs.2 and 3 for light–quark jets. It is easy to see that the shape of asymmetry is different for standard and spin-dependent pomeron vertices. In the first case it is approximately constant, in the second it depends on $p^2_\perp$. This is caused by the additional $p^2_\perp$ terms that appear in $\Delta N^{\Delta\sigma}$ and ΔN^σ in (11) for the pomeron coupling (7).

To show the possibility to determine the form of the quark–pomeron coupling ¿from experimental data, it is necessary to estimate possible errors. For this purpose the experimental sensitivity in measured single spin asymmetry obtained in [14]

$$\delta A \simeq \frac{0.1}{\sqrt{\sigma[pb]}}$$

was used. The estimated errors are shown in Fig.3. It easy to see that the structure of the quark-pomeron vertex can be studied from the $p^2_\perp$ distribution of single-spin asymmetry (the appropriate region is $1Gev^2 < p^2_\perp < 10GeV^2$).

We calculate the cross sections σ and $\Delta\sigma$ integrated over $p^2_\perp$ of jets, too. The asymmetry obtained from these integrated cross sections does not

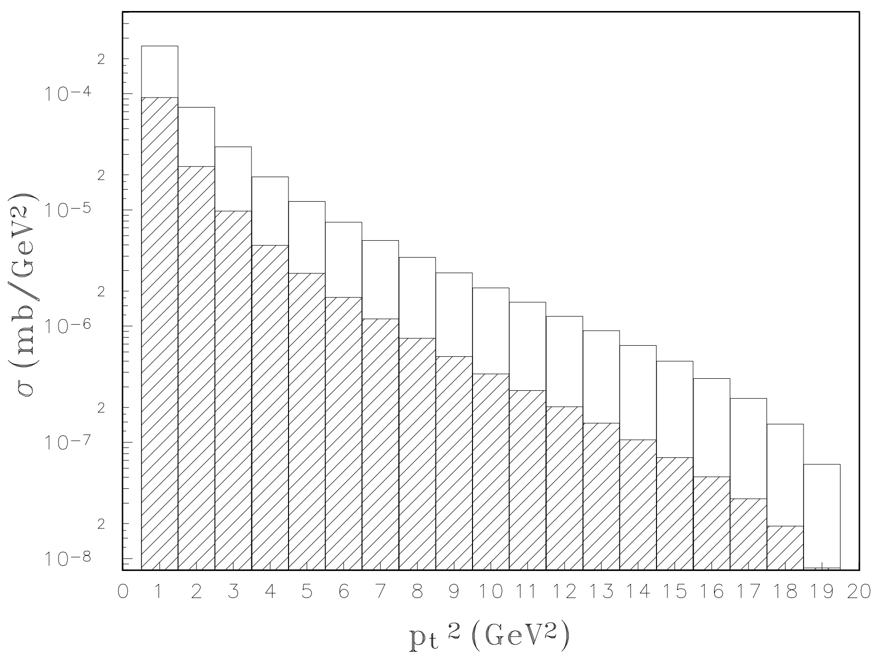

Figure 2: $p_\perp^2$ dependence of σ. Fill boxes-for standard; open boxes -for spin-dependent quark-pomeron vertex.

depend practically on the quark-pomeron vertex structure. It can be written in both the cases in form

$$A1 = \frac{\int dp_\perp^2 \Delta\sigma}{\int dp_\perp^2 \sigma} \simeq 0.5 A_\perp^h \tag{13}$$

As a result, the integrated asymmetry (13) can be used for studying of the hadron asymmetry $A_\perp^h$ caused by the pomeron.

The kinematics of the investigated reaction in the lab. system has been studied. The recoil hadron should be emitted at an angle about $40^o \div 60^o$. The typical jet angles should be $40 \div 100 mrad$. So, they can be detected by HERA-N. To detect the recoil hadron it is necessary to have the RECOIL detector for $\theta_{Lab} \simeq 40^o \div 60^o$.

Thus, in this report the perturbative QCD analysis of single spin asymmetry in diffractive 2-jet production in the pp reaction is performed. It is shown

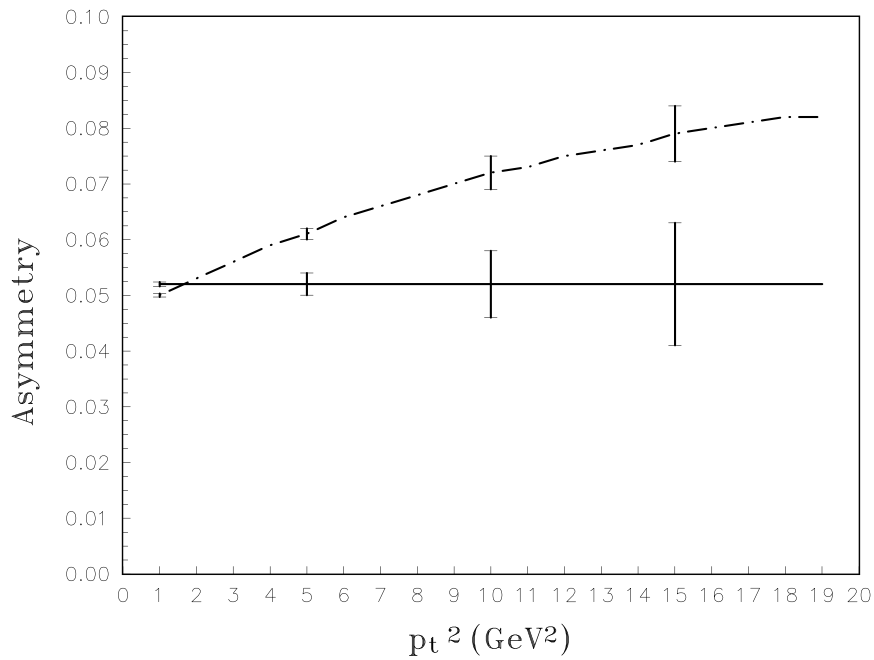

Figure 3: $p_\perp^2$ dependence of asymmetry and the estimated errors. Solid line -for standard; dot-dashed line -for spin-dependent quark-pomeron vertex.

that such experiments at HERA-N energies permit one to study spin properties of quark-pomeron and proton-pomeron vertices determined by QCD at large distances.

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